UV4Plants Bulletin

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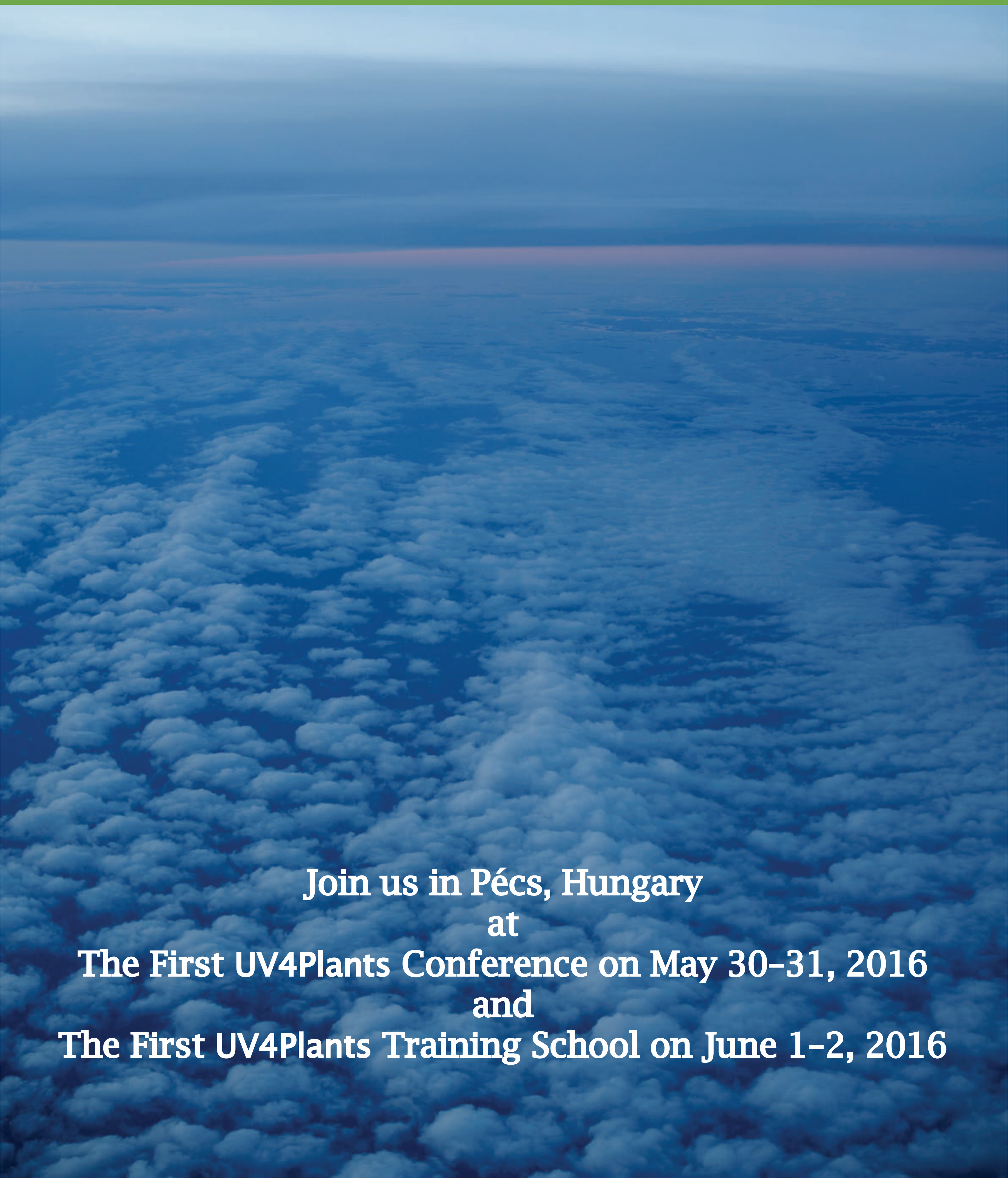

Join us in Pécs, Hungary
at
The First UV4Plants Conference on May 30–31, 2016
and
The First UV4Plants Training School on June 1–2, 2016

Volume 2015, Issue 1

UV4Plants Bulletin

An open-access publication of the UV4Plants Association

December 2015

ISSN 2343-323X

The UVP Bulletin is published by the Department of Biosciences, University of Helsinki on behalf of the UV4Plants Association. http://www.uv4plants.org/

Typeset with LaTeX in Lucida Bright and Lucida Sans using the KOMA-Script book class.
Edited with WinEdt.

Contents

From the editors' desk

Presenting our Bulletin

You are now reading the first issue of the UV4Plants Bulletin. We hope you will find the UV4Plants Bulletin entertaining and useful reading. In this first issue, we have five contributions plus the regular letter from the president as main content. One article by Alan Jones summarises earlier cases of use of the *citizen science* approach to research and discusses its possible application to future UV research. Lars Olof Björn gives a short account of the origin of the now standardized definitions of UV-A, B and C regions of the spectrum. Alenka Gaberščik reviews the new edition of *Photobiology: The Science of Light and Life*, the book edited by Lars-Olof Björn. Titta Kotilainen comments on the low frequency of UV-related presentations in horticultural conferences, and on how UV researchers could address this problem. In the last article, I briefly describe and exemplify the use of a suite of R packages being developed to easy photobiological calculations. You will also find the announcement for the first scientific conference to be organized by our association in May 2016, and a *letter from president*, giving an account of the origin of our association, a perspective on its future development and the benefits our association aims at providing to members and the research community at large.

We have given special thought to what *niche* our Bulletin should occupy in the publishing arena. We do not want the scope to overlap with that of well established scientific journals, but notwithstanding, we want the Bulletin to publish only work selected through consistent requirements of high quality and high relevance. Neither do we want the Bulletin to be a publication channels for information of short-term value, as on-line services like blogs and web sites can be more efficiently used for this.

How can this different *niche* be achieved? It can be achieved through a scope based on a different definition of relevance than used by mainstream journals. Our main criterion of relevance is based on usefulness and interest to our readership, rather than only on novelty or originality of the science reported. This opens the door to the publication of tutorials, historical accounts, opinions, and commentaries on subjects *applicable* to research in UV-photobiology and related teaching and popularization activities. We also wish to publish reports written by students and young researchers about their experiences with international mobility and their first contact with photobiological research or of the early stages of their careers. In the case of senior researchers or important stakeholders interviews by younger researchers are preferred.

The Bulletin will be open-access, which we hope will benefit both contributors and the UV4Plants Association. Members will receive a discount on the price of printed copies and will not be charged any handling or other fees. I want to highlight here that the scientific publication business is at transition point with heated ongoing debate on several issues concerning publication access, quality assessment, wrong-doing and assessment of the publication record of university staff and appointment criteria. Some recent papers reporting on bibliometric studies are both enlightening about the nature of the problem, and at first sight surprising: e.g. that non-reproducibility of published results and withdrawals due to wrong-doing are most prevalent in the those journals like *Nature* which are at the top of the ranking based on impact factor (IF) calculations (Brembs et al. 2013, and references therein). The authors' conclusion is that IF is a biased, unreliable and due to aspects of the calculations being negotiated between ISI and publishers, not an objective measure of research quality. The authors of this review propose a total overhaul of the scientific publication process. This is not the only proposal in this direction, and we hope that our young and fast-reacting in-house publication editorial and production chain, not tied to any commercial publisher will allow us to adjust and grow in this changing situation. Our willingness to 'acclimate' is also reflected in that we have no hard and fast rules on what will or will not be published.

We wish to encourage our members and outside contributors to be imaginative and broad minded in the manuscripts they submit to the UV4Plants Bulletin. Informal proposals and discussions with any of the members of the editorial board are encouraged before formal submission, especially in those cases where manuscripts seem to be near the boundary of the scope as described. We already have some proposals and promised manuscripts for the next issue. As the main format will be electronic, there are no author charges for use of color in figures, diagrams or the text body itself. Neither there are page charges for long articles. Page limits will be imposed by editors only on the base of the substance of the article—i.e. no verbosity or unnecessary repetition in the text will be accepted independently of the length of the submitted manuscript.

As said above we want to be as flexible as possible and let UV4Plant members guide the future of our publication. Consequently, any type of constructive feedback and suggestions are welcome by the editors. We will soon open an on-line feedback form for UV4Plants members to rate and comment on this first issue so as to guide us in the production of future issues.

Pedro J. Aphalo (editor)

Helsinki, December 2015.

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Letter from the President

What is next?

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My online dictionary describes "next" as "coming immediately after the present one in order, rank, or space". UV4Plants, the association for plant UV Research is the "next" one following the very successful COST-Action UV4Growth, whose funding finished in 2014. Why do we need that "next" one? To answer that question we need to look at the aims and achievements of UV4Growth. The main objective of COST Action UV4Growth was "to bring together, coordinate, and enhance the performance of nationally-funded research activities by forming a coherent, interdisciplinary research & training Network in Plant UV Biology". In practical terms, this "bringing together" of plant UV-researchers became visible in a range of different ways:

- The organisation of three large conferences (Szeged 2011, Mikulov 2013, and Bled 2014) which brought together a very large part of the European plant UV-community, as well as visitors from other parts of the world (28 countries were represented in UV4Growth).

- The integration of molecular, physiological, agronomic and ecological expertise. I strongly believe that the plant UV community is well ahead of other research communities in terms of efficient communication across organisational levels. For example, the discovery of the plant UV-B photoreceptor has already informed a broad range of physiological, organismal and environmental studies, whilst photobiological concepts such as biologically effective doses are now routinely applied by molecular biologists and physiologists alike.

- The sharing of expertise in how to manipulate UV-radiation. This has led to a fantastic "best practice" handbook (Aphalo et al. 2012) that is now obligatory reading for every photobiology student working on UV-radiation.

- The linking of researchers from universities and research stations with industry. Two stakeholder meetings (Lancaster 2012 and Odense 2014) played a key role in this process, and established contacts that will be essential for participation of plant UV researchers in Horizon2020.

- The facilitation of research exchanges, especially for young researchers. A total of 27 exchanges took place during the life of UV4Growth, many of which contributed to thesis-chapters and/or publications.

- Joint experiments such as the Europe-wide Grapevine, Arabidopsis and Lolium (Comont et al. 2012) experiments, which involved 10's of different groups across Europe

Clearly, all these forms of "bringing together" are steps in a continuous process of sharing, collaborating, and learning from each other. This is a process that has been very beneficial for the plant UV-community, as well as for many individual plant UV-researchers. Also in the coming years, key questions in plant UV-biology require joint, interdisciplinary approaches. A few examples;

- Elucidating the ecological role of UVR8 (i.e. vis á vis UV-A and other environmental factors) requires understanding of both molecular plant UV responses as well as field experimentation (Morales et al. 2013).

- Elucidating the complex role of UV-radiation in plant reproduction requires understanding of the UV-responses of plants and pollinating insects, and their interaction (Llorens et al. 2015).

- Developing the use of UV-radiation as a tool in horticulture requires understanding of crop physiology, photobiology as well as food sciences.

Thus, although COST Action UV4Growth has ceased to exist, the need to coordinate nationally-funded research remains. In this sense the launch of UV4Plants early in 2015 was a case of "business as usual". Yet, despite the similar aims of UV4Growth and UV4Plants, there is one major difference between the former COST Action and the new association. UV4Growth, thanks to the generosity of COST, was well funded. In contrast, UV4Plants has very limited resources, and depends on its members for their support. Here, I like to express a big thank you to all those UV4Plants members that have supported the association in its first year! I also warmly welcome new members (individuals or industry).

In the past months, the members of the UV4Plants management group have been busy with the administrative aspects related to the running of an association. Now that these are finalised, the focus is shifting to scientific activities. In this sense I want to emphasise that the association very much welcomes ideas from members for future activities. The association also strongly encourages members to take advantage of UV4Plants when initiating activities such as Europe (or world?)-wide joint experiments (see example UV4Growth (Comont et al. 2012)), training schools, research exchanges (why not place a call on the UV4Plants website if you are looking for either a candidate or a position) and others. Ultimately, the association will be what the members make of it! The management committee will be very happy to hear from you!

Here a flavour of what you already might expect from UV4Plants in the coming months:

- Continuous development of the UV4Plants website (http://www.uv4plants.org/)
- Development of the UV4Plant bulletin
- Organisation of an international Plant-UV conference in the early summer (May/June) of 2016.
- Development of further links with stakeholders to facilitate coordination of research activities, help academics achieve commercial impact of research, and to identify partners for EU- or national grant applications

I am particularly pleased with the first issue of the UV4Plants bulletin. The editor, Pedro J. Aphalo, has done a wonderful job in getting some excellent contributions from a variety of members. This is a great initiative for a small association, and I hope you will support this by sending in your own contribution(s) for the next issue (Guidelines see http://www.uv4plants.org/publications/uv4plants-bulletin/)!

Happy Reading

Marcel
(Marcel A. K. Jansen)

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■ First Announcement

The international association for plant UV-research, UV4Plants organises an international conference Pécs (Hungary), May 30–31, 2016

University of Pécs

Dear Colleagues,
You are kindly invited to participate in the first network conference organised by the *International Association for Plant UV-research*, UV4Plants. The meeting will be organised in Pécs, Hungary on May 30 and 31, 2016. The conference aims to capture all that is exciting about plant UV-B research, including advances of our basic understanding at the molecular, physiological and organismal levels, in terrestrial and aquatic environments, and their application in horticulture.

UV 4Plants

General information

The meeting is to be organised at the Faculty of Sciences of the University of Pécs which will celebrate its 650th anniversary in 2017. The meeting is planned for two whole days and participants are advised to arrive to Pécs on the 29th of May. A training school, aimed at early stage researchers, is currently being planned to run straight after the conference.

Pécs is the fifth largest city in Hungary, situated at the South-West of the country. Its rich history dates back several thousand years when the area was inhabited by Celts. Where Pécs now stands, several Roman wine-producing colonies were established in the early 2nd century, under the collective name of Sopianae. King Louis the Great founded the first university of Hungary here in 1367.

Travel to Pécs

Pécs is connected to Budapest by motorway (M6) and by rail. Trains for Pécs leave from Keleti railway station at the centre of Budapest. For participants arriving by air, the easiest way to reach Pécs is using one of the shuttle companies. These are door-to-door services operating 7/24 between Budapest airport and any address in Pécs. Advance booking is mandatory and can be made via the internet. Details will be provided in the next circular.

Accommodation for delegates

Pécs is a favourite tourist destination in Hungary and there are a number of hotels including budget B&B options and comfort hotels with spa. A list of recommended hotels will be posted in the next circular.

Important dates

January 1, 2016 registration open

January 20, 2016 preliminary scientific programme on the website

February 28, 2016 deadline for the early bird registration and end of refund (50%) period, after this time cancellation is not possible

Scientific committee

Prof. Éva Hideg, Prof. Marcel Jansen, Prof. Åke Strid, Mr. Gyula Czégény, Dr. T. Matthew Robson, Dr. Pedro J. Aphalo, Dr. Susanne Neugart, Dr. Laura Llorens Guasch.

Local organizing committee

Prof. Éva Hideg, Mr. Gyula Czégény, Mr. Kristóf Csepregi, Ms. Anikó Mátai, Ms. Brigitta Végh.

The option of publishing in a special issue of a peer-reviewed journal is under negotiation.

Contact for additional information

mailto:conference2016@uv4plants.org

Methods

Citizen Science: a new tool for UV-B research?

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Introduction

In recent years, 'citizen science' has emerged as an area of growing interest. Recognition of benefits for society and environmental research has enhanced interest in this approach to engaging the public and obtaining 'crowd-sourced' data. Science funding bodies, wishing to raise the profile of their activities or to justify publicly-funded science, also regard these benefits favourably. Powerful technology has democratised tools like smartphones for data collection, transmission and storage, to an extent that would have been unimaginable two decades ago. Citizen science has become an established part of the research landscape which is here to stay. A Google Scholar search for related terms ["citizen science"+ecology] reveals that publication rates in this area are rising exponentially, with the number of publications doubling in less than 4 years (Fig. 4.1). The benefits of citizen science for researchers and the public, combined with its growing acceptance as a method for acquiring data, means researchers able to use citizen science effectively will have clear advantages in enhancing the impact of their work.

Who is a citizen scientist?

From the large and conspicuous citizen science projects arising over the last decade, often supported by national publicity campaigns and involving thousands of people, it might appear these are the only citizen science approaches available. In reality, citizen science projects can operate at a range of scales and be directed at a diversity of questions. The history of volunteer-lead science demonstrates the instrumental role of 'citizen scientists' over the last few centuries, which has often taken place in low-key ways. Amateur botanists in Britain have collected plant phenology data since the 1730s, this is now used to support our understanding of climatic impacts to plant communities (Sparks and Carey 1995), and similarly bird migration data have been collected in Finland since the 1740s (Greenwood 2007). By way of example, these contributions demonstrate how citizen scientists can supply longitudinal data across potentially immense ranges of space, time and even taxa, and that such initiatives are open to anyone.

Until recently, only experienced groups of specialist volunteers were utilised for large biological recording efforts, but the public are now becoming part of this space, as the quality of data from citizen science has been repeatedly validated by studies on its accuracy (e.g. Butt et al. 2013; Crall et al. 2010, 2011). Growing confidence exists in citizen science data, such that greater numbers of people than ever before can now contribute to valid datasets of high scientific value. Potentially all layers of society, in particular, disadvantaged groups, children or senior citizens, can participate and gain useful environmental experience (Bonney et al. 2009).

Opportunities for citizen science within UV-B research

A Google Scholar search for the combined terms "`citizen science`"`+ecology+UV-B` demonstrates that UV-B ecologists have been slow to exploit this scientific momentum. Since 1994 there have been only 28 articles published using this combination of terms and no studies feature citizen science methods to collect ecosystem data on UV-B impacts. There are clear opportunities available for UV-B scientists to embrace new innovative citizen science methods to collect data. Developing research ideas suitable for citizen science projects will be the first step in this (e.g. Box 1). As a phenomenon, UV-B has close links to natural processes which interest many members of the public. The 'ozone hole' which was well publicised in media throughout the 1980s is likely to be a good lead in point for many UV-B research projects looking to connect with the public, particularly that cohort who grew up in the 1990's and may now have families themselves. UV-B also directly influences food quality, skin cancer risks, plant-insect communication and other more hidden aspects of photobiology, and it also involves numerous important interactions with global change. These topics each have strong links with the school curriculum (Gaberščik et al. 2015) and, therefore, may become engaging areas for citizen science projects to be developed that will be suitable for children, families and young adults.

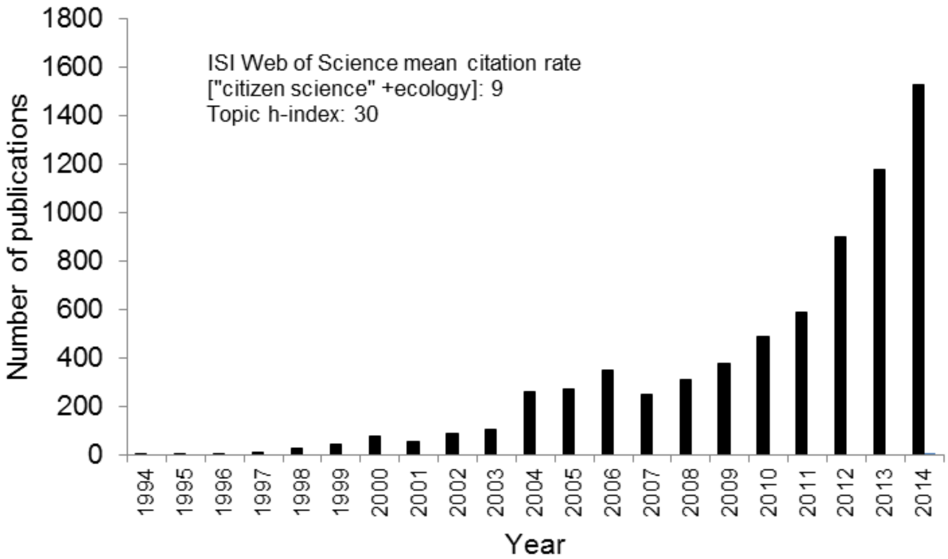

Figure 4.1: Number of publications per year with search string [“citizen science”+ecology] from a Google Scholar search.

Box 4.1: UV-B Decomposition Bag Citizen Science Experiment.
An example of how the influence of UV-B on litter quality and litter breakdown across a large latitudinal gradients could be examined using mass participation citizen science.
Approach A common plant species grown under two UV environments will produce litter that decomposes at different rates. Citizen scientists grow their plants, harvest and weigh leaf material to make decompositions bags with two mesh sizes to exclude different decomposers. Bags are provided with three different materials on the upper size that (1) exclude UV-A and UV-B, (2) exclude UV-B but transmit UV-A, and (3) transmit UV-A and UV-B. The upper UV screening material will be perforated and held away from the litter bag so that it doesn't get marked nor cause condensation to accumulate inside the bag. Decomposition bags are sent out with a dosimeter or thermopile that quantifies the UV treatment that the bags receive over the course of the experiment. Dosimeters and thermopiles are a cheap way to quantifying received UV doses – see Beyond the Visible: Chapter 3 Quantifying Radiation p78-79. Participants harvest and weigh half the bags after time period 1 (e.g. 4 months) and the other half after time period 2 (e.g. 12 months).

Why be a citizen scientist?

The motivations of participants are the key to engagement in particular research topic. Numerous projects often featuring charismatic topics close to the hearts of the public were reviewed by(Roy et al. 2012) (e.g. garden birds (Big Garden Birdwatch (Protection of Birds 2015); horse chestnut trees (Conker Tree Science (Pocock and Evans 2015)); bats (National Bat Monitoring Programme nbmp.bats.org.uk); ladybirds (UK Ladybird Survey (Roy et al. 2015)); butterflies (United Kingdom Butterfly Monitoring Scheme (CEH 2015))). Although less charismatic topics, including earthworms and soil (OPAL soil and Earthworm Survey (OPAL 2015)), or soil properties (mySoil (Survey 2015)) also feature. Motivations for potential citizen scientists are not necessarily defined by a charismatic topic, but from an opportunity to contribute meaningfully to the body of scientific knowledge. Such motivations need to be exploited and reinforced during the project. From personal experience, I find the citizen scientists I work with value an opportunity to contribute to science that might make the world a better place, and an initial goal is to develop a narrative that supports this.

To connect effectively with the data collection process, participants need to be suitably trained, so that they are sure of what they are doing and why they are doing it (Bonney et al. 2009). Citizen scientist retention on the OPen Air Laboratories network (OPAL) was found to be as low as 10 % after initial online recruitment (Butt et al. 2013), so drop-off rates in some projects may need to be factored into project planning. Effective training can, however, enhance retention and ensure participants are well-motivated during their data collection, ensuring greater validity in the data collected (Dickinson et al. 2010). Citizen scientists can be trained in tasks with a range of complexities. The most simple citizen science data gathering exercise (e.g. counts of organism presence) may only need simple instructions from an online training page (www.bigbutterflycount.org). Such more-limited approaches are likely to be unsuitable for the complex ecological questions associated with UV-B research. Face-to-face training sessions enhance the complexity of potential data gathering techniques and are suitable for smaller groups of volunteers This personal approach has hidden benefits in ensuring participants have both a stronger commitment to the project and a better understanding of the science.

Participants are also incentivised to contribute by positive feedback. When working alongside participants, the lead scientist is a mentor who can constantly update on their progress and demonstrate what has been achieved. Social media platforms can provide additional feedback for mass-participation projects, delivering instant progress reports via the internet, or smartphones.

What can citizen scientists do?

Mass-participation citizen science projects using very simple data gathering methods give an appearance that simple studies are all that can be achieved. In practice, however, complex fieldwork tasks can also be undertaken with appropriate training. The citizen-science-led UK charity, Earthwatch, for whom I work, oversees a global range of environmental projects with different levels of scientific scope (Brightsmith et al. 2008). Our long-term monitoring project at Wytham Woods, Oxfordshire, uses teams of citizen scientist executives from a large multi-national company, who collect measurements from a network of forest-carbon-dynamics monitoring plots. These nine 1-ha plots, containing 12,000 trees were also originally set up by the volunteers. I am consistently impressed in how our volunteers can learn technical field skills rapidly and complete complex data collection methods. Field work tasks in ecology are often very repetitive, so the limiting step is often simply a case of person-hours – and teams of citizen scientists are ideal to provide this. Our citizen scientists have completed tree canopy leaf area index (LAI) assessments with hemispherical cameras, near-surface imaging of vegetation, and used infra-red gas analysers (IRGA) for measuring soil $CO2$ fluxes. In spring 2015, they helped construct a 48-plot drought experiment in the woodland, installing rainout shelters, soil respiration collars and rainwater collection bottles throughout 2 ha of woodland. Adaptable and creative field work and methods can enable inexperienced fieldworkers to be trained in complex tasks with minimal supervision. This project has now successfully engaged over 1 000 citizen scientists since 2006, with 8 papers delivered through international peer-reviewed journals.

What are the limitations of citizen science?

Citizen science can deliver both data and high quality public engagement for researchers, but the limitations of working with the public and managing teams of inexperienced citizen scientists can place constraints. Temporal or spatial biases can develop in datasets as a result of ad hoc data collection (Bonney et al. 2009; Roy et al. 2012), with such imbalances being minimised, either by changes in the experimental design or by statistical analysis adjustments. Mass public participation projects are more prone to this, in contrast to smaller projects where lead scientist mentoring minimises such problems. The validity of citizen science data has been repeatedly demonstrated in studies examining their quality (e.g. Butt et al. 2013; Crall et al. 2010, 2011). A critical part of the citizen science process, however, lies in error checking of datasets to improve their quality. Error checking will identify problems with individual data points (statistical outliers), or determine whether systemic biases exist in the data. Measurements taken by inexperienced citizen scientists will have lower levels of precision than those collected by expert scientists. This can introduce random errors are into the data, creating 'noise' through which a small environmental signal might be lost (Bonney et al. 2009). Using thousands of data points collected in Wytham Woods, Butt et al. (2013) compared volunteer citizen scientist measurements with those of expert scientists. Although volunteer measurements had significantly lower levels of precision, these were random errors attributable to a difference in means of less than 1 %.

Budgeting for citizen science projects needs to consider costs and losses of citizen scientist recruitment. Some materials may go to waste if participants fail to submit data. Citizen science programmes may require an unexpectedly large investment of the lead scientist's time spent training volunteers, or completing numerous administrative tasks. An important aspect to be addressed at every development stage is risk management and the need for participant safety. Experimental protocols may firstly need to be carefully assessed, not only to ensure scientific efficacy, but also to examine where any risk to participants lies. Protocols may need to be reviewed throughout the programme to manage risks as they develop. Pilot studies at the outset of a project are useful, where participants can be observed in action so that any unforeseen risks are identified and necessary adjustments made.

Moving forward with citizen science

In terms of UV-B research, citizen science has great potential value as a tool for collecting data along spatially-extensive natural UV-B gradients. Latitudinal transect studies, as used by the UV4Growth consortium (Hauser pers. comm.); Comont et al. (2012) and Ruhland et al.

Figure 4.2: Earthwatch citizen scientists measuring tree growth rates from one of 12,000 trees in Wytham Woods, UK

Figure 4.3: Face-to-face contact with citizen scientists enables highly technical data-gathering methods to be used: here training in infra-red gas analyser (IRGA) use for carbon dynamics assessments in Wytham Woods, UK.

(2013), could be adapted for citizen scientists using simplified protocols. Regions, such as Europe, with large latitudinal ranges and high population densities, provide a clear opportunity for citizen science investigations on how large UV-B gradients influence plant ecology. Such studies could take the form of surveys, or common-garden mesocosms, to determine growth responses in key plant species. Photodegradation of plant litter by UV-B is another key area where latitudinal UV-B gradients be could utilised by citizen science experiments. A citizen science method developed by researchers at Utrecht University using the simple technology of tea bags as decomposition assays, is being used to provide a global assessment of decomposition rates in soil (Keuskamp et al. 2015). A similar decomposition assay method could be adapted to investigate UV-B impacts on above-ground decomposition rates via a UV-B latitudinal gradient and mass participation from citizen scientists (Box 1).

Citizen science is now an established and adaptable tool for researchers. It has growing scientific momentum and increasing validity as an accepted form of data collection. Effective use of citizen scientists comes from identifying opportunities for specific research that will engage the public. An array of citizen science models can be used to support diverse projects operating at a range of spatial and temporal scales, but practical limitations of the citizen science approach need to be recognised. Methodologies should be adaptive and subject to constant review based on participant performance. Citizen science is now embedded within many areas of ecology, but ecological UV-B research has so far been slow to take up this initiative. UV-B researchers now have an opportunity to develop new ways of working that will exploit the power of citizen science engagement and increase knowledge of the importance of UV-B in plant biology.

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Book Review

Photobiology: The Science of Light and Life (ed. Lars Olof Björn)

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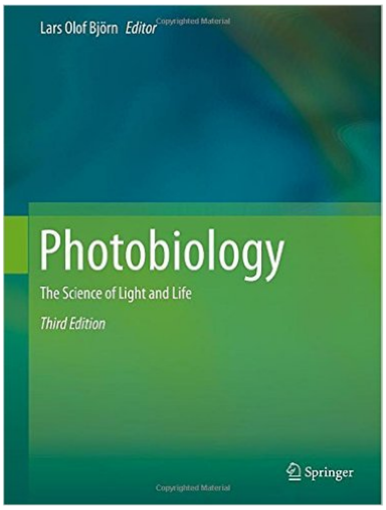

Light that comes from the Sun is of crucial importance for life. It is the driving force of the biosphere, serving as a source of energy for organisms and providing them with information about their environment. On the one hand, plants harvest light in the process of photosynthesis, and on the other hand, light directs plant development from germination to flowering. Light also has both warming and destructive effects on plant tissue. Plants can sense the quality, intensity, duration and direction of light through different sensors, while in animals, light provides information via vision. Different wavelengths of light have different effects on organisms.

The book *Photobiology: The Science of Light and Life* is edited by Lars Olof Björn, a Professor in the Department of Biology at Lund University, and in the School of Life Sciences at South China Normal University. He is a scientist with long-standing experience in photobiology research. His research is mainly concentrated on the photobiology of plants, but he is also interested in animal vision, skin photobiology, and bioluminescence. Lars Olof Björn is not only the book's editor, he is also an author or co-author of 22 of the 29 chapters. This is the third edition of this book, although it differs significantly from the first two editions in terms of the illustrative material, and also the full contents. The illustrative material is much richer than in the previous edition, and it also includes colour photographs and drawings. There are also several new chapters that have now been added: "Photoactive proteins", "Photoreceptive proteins and their evolution", "Signalling crosstalk under the control of plant photoreceptors", "Photosynthetic light harvesting", "Light-promoted infection", and as the last the chapter, which is very informative for UV scientists, "Role of ultraviolet radiation in the origin of life". This book is a comprehensive guide to the understanding of the nature of light and the structural and functional adaptations of organisms regarding their interactions with light.

Much of this book focuses in one way or another on the interactions between light and organisms, although the introductory chapters (from 1 to 7) also describe some common aspects of light: the interaction of light with matter, principles of nomenclature for quantification of light, generation and measurement of light, light as a tool for scientific research, and the properties of light in terrestrial and aquatic environments.

The second part of this book deals with the structural and functional properties of biota in relation to interactions with light, and this very comprehensively deals with different levels of organisation, from molecules to organisms.

Chapter 8 is entitled, "Action spectroscopy in biology", which is a method that serves to identify the kind of molecules that absorb active light. The action spectrum is the rate of a physiological activity plotted against the wavelength of light, and this can also be used to identify the effects of certain wavelengths on physiological activities. This knowledge is especially important in planning experiments with light sources under controlled conditions, including in UV research.

Then chapters 9 and 10 deal with spectral tuning in biology. Spectral tuning is important for photosynthesis, animal vision, plant-pollinator interactions, and bioluminiscence. These chapters answer the questions of why plants are green, what determines the spectra of pigments, how different pigments and vision are tuned, and how different biotic structures reflect and scatter light as well as forming structural coloration, whiteness and transparency.

Chapter 11 concentrates on the photoactive proteins that are responsible for a variety of different mechanisms in plants, such as light-regulated enzymatic activities, light-driven ion pumps, light-regulated ion channels, photosynthetic light harvesting, photoreception and bioluminescence.

Chapters 12 and 13 discuss light perception and regulation in organisms. In zoology, the term photoreceptors refers to cells that respond to light (like the cones and rods in human eyes), while in plant science, photoreceptors refers to the pigment molecules that absorbs light and cause a sequence of different reactions related to this "information". Special attention is given to specific problems and evolutionary solutions in the animal kingdom, like eyes in water, chromatic aberrations, eyes of amphibians, insect eyes, eyes with mirror optics, and scanning eyes.

Chapter 14 focuses on signaling cross talk under the control of plant photoreceptors describing the basic structure and molecular mechanisms of different light signaling. Chapter 15 titled "The diversity of eye optics" is a review of different solutions to 'eye design' in the animal kingdom.

Chapters 16 and 17 summarise the important information about photosynthesis, the process in which plants harvest solar energy. Chapter 16 deals with evolution of photosynthesis and its environmental impact, which is important from the point of view of human interference in the environment and from the aspect of plant production. Photosynthetic light harvesting is presented in Chapter 17, which focuses on photochemical energy transduction in plants.

The title of Chapter 18 is, "How light resets circadian clocks". This chapter provides an overview of circadian rhythms in different organisms, such as fungi, cyanobacteria, algae, seed plants, animals and humans, and how these use the specific diurnal and annual cycles in their environment to their advantage. Special attention is given to practical problems related to circadian rhythms in humans, like shift work, jet lag, and sleep disorders. In this chapter alone, the authors cite more than 700 relevant references.

Chapter 19 provides an insight into processes related to photomorphogenesis and photoperiodism in plants. As sessile organisms, plants use the information about their environment based on the light conditions. Therefore, as well as photosynthesis, light has multiple effects on plants, including those on germination, apical hook opening, stem elongation and leaf expansion, pigment production, regulation of stomata, bud dormance, and branching and flowering. Light also serves as important information in combination with the magnetic field.

Chapter 20 is entitled, "The light-dependent magnetic compass", and it discusses magnetoreception processes that depend on light, from the behavioural, physiological, neurobiological and biophysical points of view.

Chapter 21 is dedicated to phototoxicity. Phototoxicity indicates something that is not toxic but becomes toxic by exposure to light. This chapter includes different subsections that discuss phototoxicity in plant defence, phototoxic drugs and cosmetics, and metabolic disturbances that can lead to phototoxic effects. A significant part of this chapter is dedicated to polycyclic aromatic hydrocarbons as phototoxic substances in aquatic environments, where their toxicity arises after exposure to UV-B radiation.

Although many of the previous chapters also mention UV-B radiation from different aspects, chapter 22 concentrates on the reasons and consequences of ozone depletion on life, while chapter 27 is an interesting read about the role of UV radiation in the origin of life.

Chapters 23 and 24 are also related to the effects of UV-B radiation. Chapter 23 deals with photobiological and ecological aspects of vitamin D, while chapter 24 deals with photobiology of human skin, including immunosuppression and some photosensitivity disorders. It is well know that UV radiation and other wavelengths can kill microorganisms, but there is less evidence of their positive effects.

A short chapter 25 entitled, "Light-promoted infection" then provides examples of these effects and how they are related to different organisms.

Chapter 26 is about bioluminescence, which occurs in different groups of organisms, and mainly in those living in the sea. Bioluminescence has various roles, like reproduction, protection against predation, food acquisition, protection from reactive oxygen species, and DNA repair. In addition to bioluminescence, this chapter discusses the mechanisms of light production, bioluminescence control, and human exploitation of bioluminescence.

The last two chapters (chapters 28 and 29) summarise some practical aspects that can be used in the teaching process, including including instructions on how to build an "amateur scientist's spectrophotometer".

This extensive book is a unique compilation of knowledge on the science of light and life, and it offers an exciting new perspective in photobiological research. This book is filled with concrete examples from accross levels of the hierarchy of biological organisation. This book will be of interest for many different readers, such as students and university teachers, and also scientists, not only from the field of photobiology, but also from other scientific fields.

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History

Ultraviolet-A, B, and C

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The terms ultraviolet-A, ultraviolet-B, and ultraviolet-C radiation (UV-A, UV-B, UV-C) were probably conceived during discussions at the Second International Congress on Light in Copenhagen 1932 (see historical account by Daphne Vince-Prue and David O. Hall (1975) available at http://iuphotobiology.com/history.html). The definitions of the UV bands adopted by the CIE (Comité International de l'Éclairage) are UV-A, 315–400 nm; UV-B, 280–315 nm; UV-C, 100–280 nm. Radiation of wavelength between x-rays and 200 nm is usually termed vacuum ultraviolet, but different terminology is still used in different branches of science, and no consensus exists regarding the delimitation between vacuum ultraviolet and x-rays. The terms UV-A, UV-B and UV-C are used mainly by biologists, and the reason for keeping them mainly relates to the spectral properties of DNA and of ozone, both of which have absorption peaks near 260 nm with tails extending through UV-B, but of minor importance in UV-A. The absorption of solar radiation by stratospheric ozone and oxygen is so strong throughout UV-C that none can be measured at the Earth surface. The UV-B component of sunlight reaching ground level, on the other hand, is strongly dependent on the (very variable) amount of ozone, while UV-A is not much affected. Of course, nothing changes abruptly at 280 or 315 nm, but it is important to consistently use these limits when discussing amounts of radiation.

Sometimes scientists, and in particular American scientists, have departed from the original definitions of the UV bands, which has caused (CIE 1999) to repeatedly emphasize the importance of sticking to the original definitions in order to avoid confusion. A discussion on photobiological terminology has been published by Sliney and CIE 2007. Urbach (N.D.) gives details on the original operational definition based on filters and type of sensor to be used for each of the UV bands.

It should be emphasized that extending the range of UV-B from 315 to 320 nm is no minor change. In fact this shift in the wavelength used as boundary can more than double the amount of ambient radiation included in UV-B, both whether expressed on an energy or on a photon basis (Figure 6.1). Using the same name for quantities differing this much, invites serious misunderstanding.

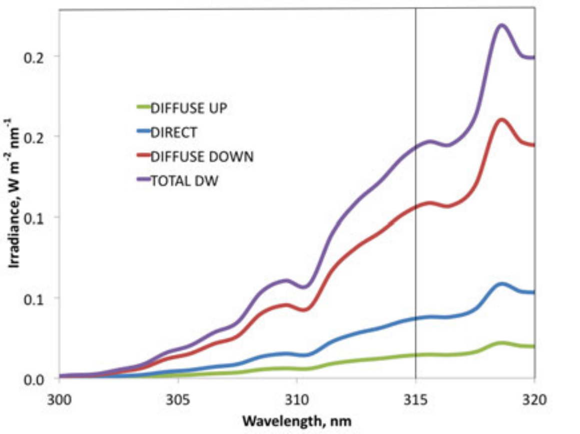

Figure 6.1: Spectra for the short-wavelength end of daylight calculated using the Quick TUV Calculator of the NCAR Earth System Laboratory (http://cprm.acd.ucar.edu/Models/TUV/Interactive_TUV/) with the following conditions: Sea level, 45° zenith angle (i.e. 45° solar elevation), 300 DU of ozone, ground albedo (reflectivity) 0.1 and cloudless sky (other conditions as calculator default). TOTAL DW stands for total downwelling radiation. The vertical line marks the upper limit of the UV-B band. Total UV-B irradiance in this case is 0.896 $W m^{-2}$. Between 315 and 320 there is 0.931 $W m^{-2}$. i.e. slightly more than true UV-B. Including this extra amount would thus more than double the value.

From Figure 6.1 it can also be seen that (under these conditions) diffuse radiation dominates the daylight UV radiation. Lindfors and Ylianttila (2015) give a visual demonstration through photographs of the relatively larger proportion of diffuse radiation in the UV region of the solar spectrum at ground level compared to that in the visible region. Thus in the shadow from direct sunlight UV-radiation may decrease much less than VIS-radiation.

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Commentary
Interaction within and between communities

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While doing my PhD thesis some years ago, I attended the *American Society for Photobiology* meeting in Puerto Rico and the *European Society for Photobiology* meeting in Bath. Since completing my PhD thesis, the congresses I have participated in have been orientated in the field of applied sciences, mainly horticulture. In 2014, I attended to the *American Society for Horticultural Science* meeting in Orlando. There were in all 49 different sessions, each having about 5-7 oral presentations and 5-7 posters. Two oral presentations and three posters were related to UV effects and exploiting their possibilities in horticulture (Box 7.1). The 2015 American Society for Horticultural Science in New Orleans hosted dozens of sessions and a myriad of presentations and poster, two of which were related to UV effects (Box 7.1). A recent issue of *HortScience* published half a dozen articles, highlighting proceedings from the 2014 *ASHS* meeting colloquium and workshop, related to LEDs and horticultural science (Massa and Norrie 2015). UVB and UVR8 get mentioned and some application possibilities are briefly outlined by Folta and Carvalho (2015).

Conferences or sessions within conferences, specialized in (UV) photobiology, demonstrate the enormous amount of information and lessons learned over the years from scientific work. There have been presentations and publications on how to transfer this knowledge to agricultural and horticultural applications, but they have been largely presented *within* the photobiological research community. The more-applied community then have their own branch of UV-related studies, but these researchers do not necessarily concentrate solely on studying and utilizing UV-related effects. When the latest results are presented within the respective communities, one can argue that there is a lack of knowledge transfer.

Based on my experience, I would say we need more conferences like the one organised by the President of *Association of Applied Biologists*, Professor Bill Davies in Lancaster during June 2015. Invited speakers and other presentations covered a plethora of subjects under the theme, “from research to the food supply chain”, ranging from lessons learned from breeding efforts for higher photosynthetic efficiency, biological control of pests in Africa, using farmer networks, all the way to exploiting photobiology in protected cropping (Association of Applied Biologists 2015).

Box 7.1: UV-related oral and poster presentations at the two most recent meetings of the *American Society for Horticultural Science*

ASHS 2014

- Exploring Plant-UV Interactions with Greenhouse Tomatoes: Stress, Flavor, and Phytochemicals by M. Dzakovich and C. A. Mitchell (Oral)
- UVB Radiation Affects Intumescence Development in Ornamental Sweet Potato (*Ipomoea batatas*) by J. Craver et al. (Oral)
- Watermelon-based Sunscreen Blocks UVA and UVB Light by P. Perkins-Veazie and A. Davis (Poster)
- The Effect of Multi-wavelength Light-emitting Diode Lighting on the Growth Response of Leaf Lettuce at Different Stages by C.-L. Chang (Poster)
- Glucosinolates Are Enhanced by Controlled Application of Abiotic Stresses in Broccoli (*Brassica oleracea* var. *Italica*) during Postharvest Storage by A. Duarte Sierra (Poster)

ASHS 2015

- Phenylalanine and Abiotic Regulation of Early Defense by K. Warpeha (Oral)
- Analysis of Effect on Harmful Microorganism Death Rate According to Ultraviolet Irradiation and Sterilization Condition of Substrate for Cultivation of Oyster Mushroom by I. S. Baek et al. (Poster)

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Folta, K. M. and S. D. Carvalho (2015). ‘Photoreceptors and Control of Horticultural Plant Traits’. In: *HortScience* 50.9, pp. 1274–1280.

Massa, G. D. and J. Norrie (2015). 'LEDs Electrifying Horticultural Science: Proceedings from the 2014 Colloquium and Workshop'. In: *HortScience* 50.9, pp. 1272–1273. eprint: http://hortsci.ashspublications.org/content/50/9/1272.full.pdf+html.

Methods

The r4photobiology suite: spectral irradiance

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Introduction

R is a language designed for data analysis, and it has become in recent years the most popular software for advanced statistical analysis. With some delay, it is now also being incorporated into most university level curricula (?) and even in some cases being taught in high schools (Dennis 2013). Nowadays it is also widely used in financial institutions, industry and the big players in the cloud services. Microsoft has bought *Revolution Analytics* and has released its own distribution of R, called `Revolution R Open` (RRO). Currently R is world's most widely used statistics programming language (?).

I started using R more than 15 years ago. At those times R was not as popular as it is nowadays and most people considered it to be too difficult to be taught at the undergraduate level. By year 2001 I was already using exclusively R for data analyses related to my own research. Teaching SPSS felt awkward to me: why use in teaching software that I did not find suitable for my own research? This is how my first course specifically on R, and the use of R in my statistics courses started. At the time I was at the University of Jyväskylä.

Many scripts and bits of R code my students and myself were using for analysing spectral data accumulated over these nearly 20 years. By the time Beyond the Visible: A handbook of best practice in plant UV photobiology (2012) was published I had started organizing these bits of R code. Simultaneously with this handbook, I wrote an R package called `UVcalc`, which was described in it.

In several of the training schools organized by the UV4Growth COST action FA0906 "UV4Growth" we taught how to do calculations related to the quantification of UV radiation using R. This provided very good feedback that allowed me to design a much better user interface. In parallel, in a project I am collaborating with T. Matthew Robson, we need to process close to a million measured radiation spectra, which pushed me to optimize calculation speed. Early on it became clear that the use of the algorithms we were using was not limited to UV radiation or plants, which lead to a broadening of the aims of this development.

During these three years both the user interface and how calculations are implemented in the R code have been improved. In addition the range of calculations implemented has been greatly expanded. Given the amount code and data now available, they are now split between several different R packages, conforming a suite. I call it the R4Photobiology suite of packages (Aphalo 2015a). The core packages are already well tested and stable, so I have presented the suite at two conferences: a talk at the UseR! 2015 conference (Aphalo 2015b) and a poster at the European Society for Photobiology Congress (Aphalo 2015c). At the UseR! 2015 conference I received very useful comments that lead to the addition of new functionality into the packages.

The main focus of the suite is the processing of spectral irradiance data required for quantification of radiation in photobiological research. There is in addition support for calculations related to tri-chromic vision and the position of the sun, such as day and night length. In the section I describe the data flow and how it relates to the calculations implemented in the suite.

Data flow

In this note I focus on spectral irradiance measurements, however, the suite includes functions for summarizing and combining different types of spectral data. It also has some support for estimating responses by organisms. These include photoreceptor-related calculations and vision in humans and other organisms. Functions for calculating the position of the sun, and day and night length are also included.

In broad terms the steps are A) acquisition of raw spectral data, B) processing into calibrated and validated spectral data, including exploratory analysis of spectra, C) summarizing of the spectral data, including spectral weighting, integration over wavelengths, smoothing, feature extraction; D) statistical analysis. The suite mainly focuses on steps B) and C) (Fig. 8.1.

A In the case of spectral irradiance, the first step is the acquisition of data, either with a spectroradiometer or by simulation with a model. The suite includes functions for reading output files produced by Ocean Optics instruments (OceanView, SpectraSuite), Macam instruments, Avantes instruments, and the old LI-COR spectroradiometer. Import of data output from TUV and LibRadTrans models is also possible. In addition, R can read natively `.csv` files (comma separated values) and with contributed packages out from MS-Excel and many other data formats. Usually calibrations are applied in the instrument firmware, or in software supplied with the instrument. At the moment support in the suite for these steps is limited to what we use ourselves because these steps tend to vary from instrument to instrument and in time.

B Classes for storing spectral data, definitions of operators and functions for mathematical operations for tarnsfroming spectra and for operations between spectra and between spectra and numerical data, and functions for automatic plotting of spectra are specially important for this step. Much of the code in the suite is needed to provide these facilities.

C "Apply" methods to apply arbitrary R functions to spectral data, functions for integration of spectral data over wavelengths, for smoothing and normalizing spectral data are supplied for this step. In addition to general-purpose functions for integration, functions for the calculation of specific summary quantities like irradiance and fluence are frequently used at this step.

D Statisitical analysis is the core of R, so base R functions and those in other contributed R packages can be used at this step. The suite does not add to these.

Design

I had two main aims guiding my design decisions for the suite: 1) robust data handling and reproducibilty, 2) achieving easy of use through a consistent interface. The first aim is achieved by incorporating "sanity tests" for the data and by storing metadata, together with the data. So as to simplify the user interface, the data is always stored SI units without scale factors, e.g. $\mathrm{mol\,m^{-2}\,s^{-1}}$ instead of $\mathrm{\mu mol\,m^{-2}\,s^{-1}}$. Algorithms have been carefully selected or designed so as to minimize rounding and interpolation errors, sometimes at the expense of performance.

Spectral data are stored in objects of classes defined in package photobiology. In these objects data are stored in a consistent way—same quantity expressed in the same units—using always the same variable names for wavelengths and quantities. The hierarchy of classes used to store spectral data is shown in Figure 8.2. These classes are for individual spectra of a given type. Another hierarchy of classes is used to store collections of spectra—more precisely collections objects of classes defined to store individual spectra. They have related names. For example, in the case of spectral irradiance we have `source_spct` for individual spectra and `source_mspct` for collections of spectra of this type. Many methods are implemented with the same name for both individual spectra and for collections of spectra.

Another key concept used throughout is that of 'waveband'. In the suite it is used with a broader meaning than usual: a 'waveband' always describes weights for a range of wavelengths, in the simplest case, weights are equal to one for observations within the range of interest, and zero otherwise. In the case of *effective* irradiance, weights can take arbitrary values, defined either by mathematical function or by tabulated multipliers. These weights are called in general *spectral weighting functions* (SWFs), or when derived from biological action spectra *biological spectral weighting functions* (BSWFs). The suite defines a class for storing such information, called `waveband`. Combining different spectral objects holding data, wavebands containing the weights to apply and functions defining integration procedures, it is possible to very flexibly quantify radiation. Furthermore, the user can create new flavours of any of these three types of objects. This approach gives consistency and orthogonality to the user interface, minimizing the number of 'names' that need to be remembered without sacrificing flexibility in what calculations can be done.

Additionally, the second aim is further supported by many different methods and functions having the same 'argument signature', in other words the position and names of formal arguments are the same across many functions. The use of classes, allows the coexistence of methods with the same name, which are automatically dispatched according to the type of spectral data. Finally implementing operators such as '+' for spectra makes user code much simpler by removing the need of using loop constructs like `for` and `repeat` statements in user scripts.

Packages

The suite consists in 12 packages, of which one is just a 'loader' of the other packages. All other packages depend on the one called photobiology. Other packages provide functionality or data specific to a subject area of research or a certain type of calculations. I expect that myself and other contributors will write new packages extending the suite.

The package at the core of the suite, called photobiology, implements generally useful data classes, methods and functions for photobiological calculations. It contains only the minimal amount of example data needed for examples in the documentation and code tests. As of current version 0.8.10, it exports 228 method and operator definitions—using less than 40 new names, 221 function definitions, and 17 classes.

Another broadly useful package is photobiologygg

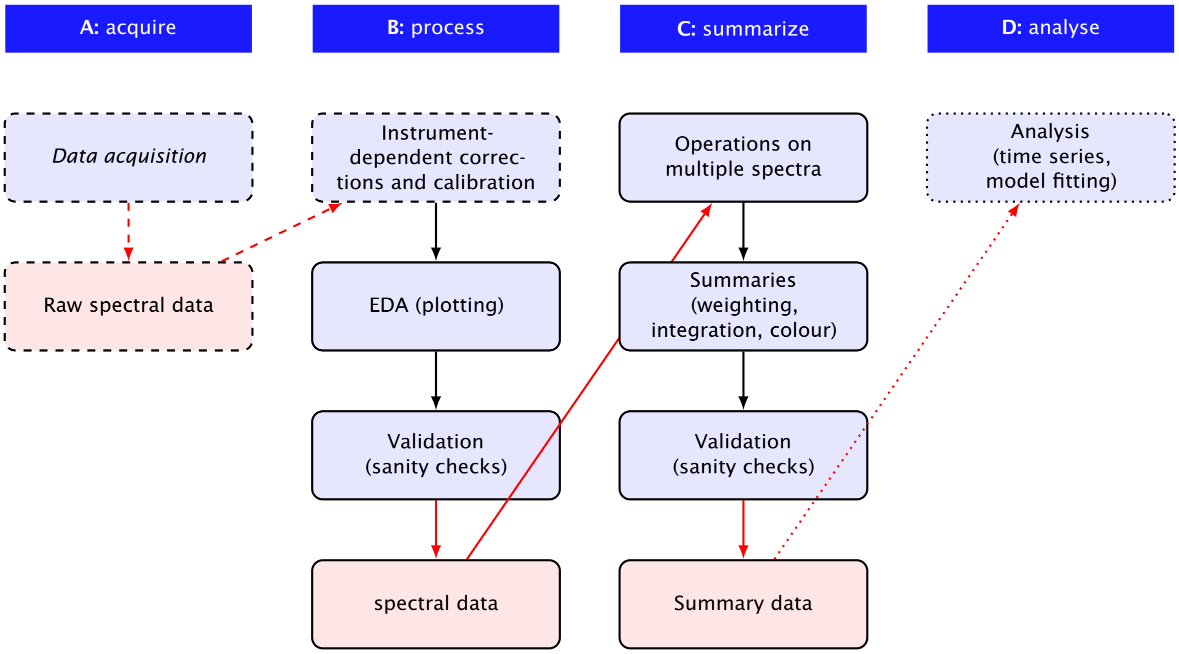


Figure 8.1: Diagram of the data flow for analysis of spectral irradiance.

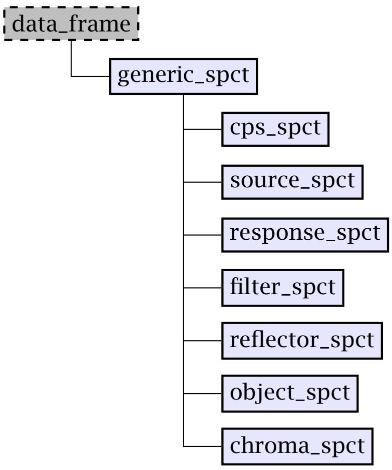


Figure 8.2: Classes for storage of data of different spectral quantities

which implements plotting of objects of the spectral data classes defined in package photobiology. The plotting functions are extensions to Hadley Wickham's package ggplot2, currently the most popular of R's plotting systems. It defines only 9 new names, and defines special `plot()` methods for seven classes of spectral objects.

A third broadly useful package is photobiologyWavebands proving constructors for frequently used definitions of wavelength bands and BSWFs. Other packages are more specialized, for example photobiologyPlants proving functions and data useful in plant photobiology and photobiologyFilters containing a large collection of spectral transmittance data for filters and materials.

Use examples

In this section we provide R-code examples for printing and summarizing spectral data (Box 8.1), plotting spectral irradiance (Box 8.2), calculating and plotting effective spectral irradiance (Box 8.3) and calculating and plotting effective spectral irradiance for polycarbonate-filtered solar radiation (Box 8.4, one final example exemplifies how to calculate daily effective exposures under different filters (Box 8.5. The intention of presenting these examples is to demonstrate the simplicity of the code needed to do some frequently used calculations. In these examples we have used only data supplied by packages in the suite, which is a suitable approach for teaching or planing of experiments. For describing real experimental conditions one should use newly measured spectral data. A final example demonstrates how to read data from a file output by a Macam spectroradiometer (Box 8.6).

Resources

A web site dedicated to the `r4photobiology` suite, located at `http://www.r4photobiology.info/` provides installation instructions. Each of the packages contains one or more vignettes like User Guides and/or catalogues of the included data examples, and the individual methods, functions, operators and data objects have been documented with help

Box 8.1: Example code for printing and summarizing spectral data.

Print spectral data for sunlight included in package photobiology. Compared to the usual R print-out we included, in part thanks to package `dplyr`, additional information including time and geolocation of measurement when available.

```
print(sun.spct)

## Object: source_spct [522 x 3]
## Wavelength (nm): range 280 to 800, step 0.9230769 to 1
## Measured on: 2010-06-22 09:51:00 UTC
## Measured at: 60.21 N, 24.96 E
## Time unit: 1s
##
##    w.length s.e.irrad s.q.irrad
##       (dbl)     (dbl)     (dbl)
## 1     280.0         0         0
## 2     280.9         0         0
## 3     281.8         0         0
## 4     282.8         0         0
## 5     283.7         0         0
## ..      ...       ...       ...
```

The `summary()` method for spectra also outputs additional information compared to R's `summary()` method for data frames.

```
summary(sun.spct)

## Summary of object: source_spct [522 x 3]
## Wavelength (nm): range 280 to 800, step 0.9230769 to 1
## Measured on: 2010-06-22 09:51:00 UTC
## Measured at: 60.21 N, 24.96 E
## Time unit: 1s
##
##     w.length      s.e.irrad        s.q.irrad
##  Min.   :280   Min.   :0.000   Min.   :0.00e+00
##  1st Qu.:409   1st Qu.:0.411   1st Qu.:1.98e-06
##  Median :540   Median :0.580   Median :2.93e-06
##  Mean   :540   Mean   :0.516   Mean   :2.41e-06
##  3rd Qu.:670   3rd Qu.:0.666   3rd Qu.:3.15e-06
##  Max.   :800   Max.   :0.821   Max.   :3.37e-06
```

pages accessible through R's built-in documentation system. A handbook on *Photobiological calculations with R* is being written by myself, Andreas Albert, Titta Kotilainen and T. Matthew Robson. A draft version will be made available on-line in early 2016, and the final version published in the Autumn of 2016.

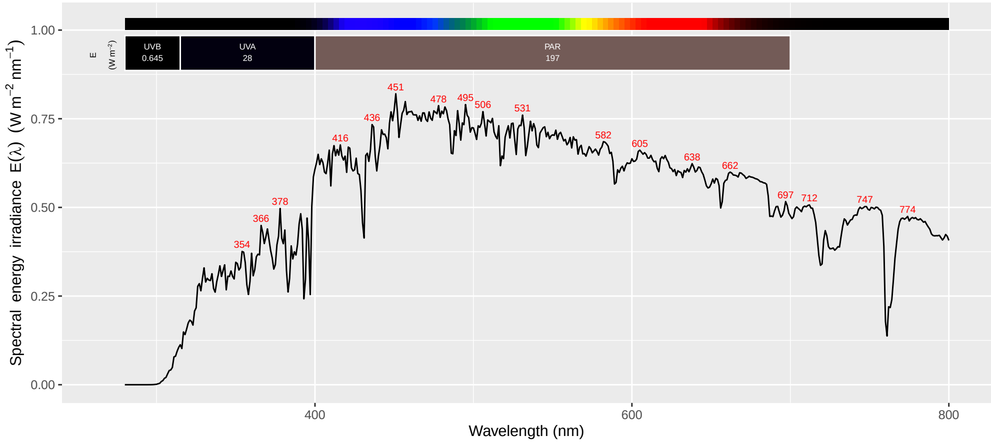
Acknowledgements

The development of the suite has benefited from earlier work by many different people. From the point of view of R code development and coding, the packages and books written by Hadley Wickham have been of enormous importance. It is also necessary to acknowledge the contributors to the development of R itself, and the openness of the whole R community for sharing information and tips and their willingness to help through on-line forums. From the perspective of photobiological calculations themselves, many members of the UV4Growth COST Action have contributed 'problems' with their questions, and/or data and use examples that have been very useful for the design and testing of the suite. Some people need to be mentioned specially for their contributions related to algorithms used for calculations and discussions about reliability and reproducibility: Andy McLeod, Lars-Olof Björn, Lasse Ylianttila, T. Matthew Robson and Anders Lindfros where the main contributors on these aspect. Titta Kotilainen and T. Matthew Robson have been my *guinea pigs* always willing to give quick feedback on my sometimes not so wise design decisions and showing my new uses of my own code. Other members of the Action, specially the students in the training school have contributed very useful feedback, sometimes in writing and other times with their questions and facial expressions during training events. Several companies and researchers have allowed the inclusion of their data in the suite. They are acknowledged in the documentation. There is one additional person to thank: Nigel Paul. A chat with him at one of the first UV4Growth meetings where we exchanged ideas about the need of making these type of calculations easier, and to improve the reliability and

Box 8.2: Example code for plotting of spectral irradiance and spectral transmittance.

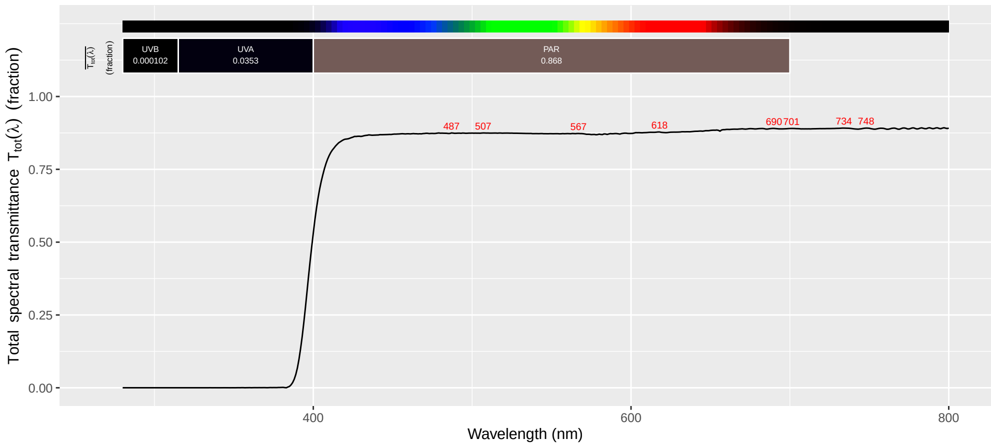
Plot of spectral irradiance of sunlight, using example data included in package photobiology.

```
plot(sun.spct)
```



Plot of spectral transmittance of 3 mm-thick polycarbonate example data included in package photobiologyFilters. We trim the wavelength range of the filter data to match the range of the solar irradiance data, so that the x-axis is identical in the three figures.

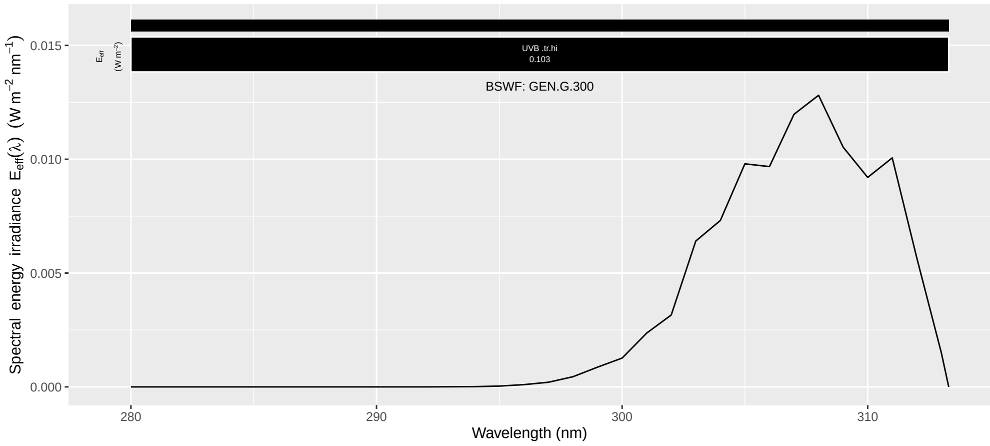
```
plot(trim_spct(foiltek.mspct$Clear_PC, range=sun.spct))
```



Box 8.3: Example code for plotting biologically effective spectral irradiance.

Plot of spectral (energy) irradiance of sunlight weighted with the generalized plant action spectrum according to Green's formulation normalized to 300 nm, using example data included in package photobiology.

```
plot(sun.spct * GEN_G(300))
```

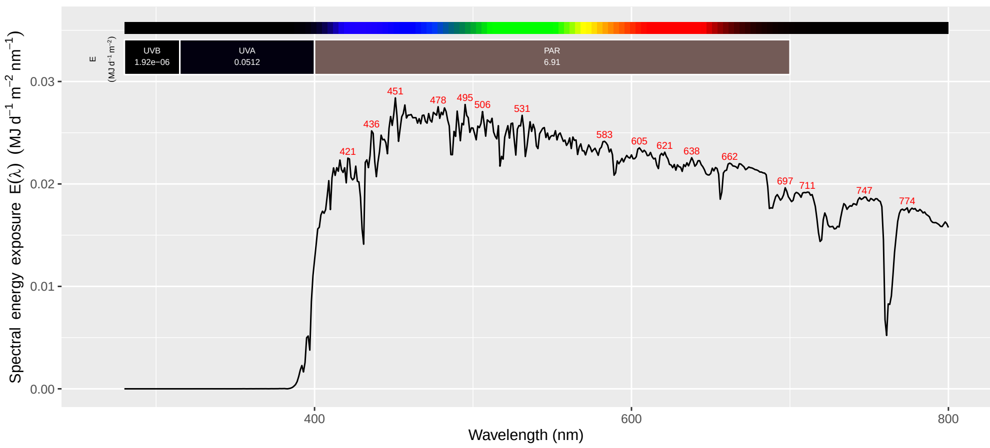


The labelling of the y-axis adjusts to the data and a label with the SWF is also added.

Box 8.4: Example code for estimation of spectral irradiance under a filter. Comparison of sunlight and sunlight filtered by a polycarbonate sheet.

We convolve the two spectra plotted in Box 8.2 using operator * to simulate spectral irradiance of filtered sunlight under the polycarbonate filter and plot the resulting spectrum with correctly labeled axes.

```
plot(sun.daily.spct * foiltek.mspct$Clear_PC)
```



Box 8.5: Example code for estimation of effective daily exposures. Comparison of sunlight and sunlight filtered by different filters.

The calculation of a effective irradiance value consists in applying a wavelength-dependent weight to spectral irradiance to obtain an effective irradiance spectrum, and then integrating this weighted spectrum over defined range of wavelengths. The equation below shows this expressed mathematically.

$$I_w = \int_{\lambda=\lambda_{\min}}^{\lambda=\lambda_{\max}} I(\lambda) \times w(\lambda) \mathrm{d}\lambda \qquad (8.1)$$

where I_w is an *effective* irradiance in *weighted* $\mathrm{W\,m^{-2}}$, λ is wavelength in nanometres, $I(\lambda)$ is the spectral irradiance in $\mathrm{W\,m^{-2}\,nm^{-1}}$, $w(\lambda)$ is a dimensionless **spectral weighting function** (SWF).
The code chunk below applies equation 8.1 to solar spectral irradiance example data using the CIE98 spectral weighting function for erythema. Here we use `e_irrad()` to calculate energy irardiance. A function `q_irrad()` is available for photon irradiance. The predefined function `CIE()` returns a `waveband` object implementing the CIE98 weighting function. Other similar functions for other SWFs are also defined in package photobiologyWavebands and in addition users can define arbitrary definitions of both weighting functions or wavelength ranges.

```
e_irrad(sun.spct, CIE())

##  CIE98.298.tr.lo
##          0.08182
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy irradiance total"
```

We rarely need to calculate a single effective irradiance value, so methods in package photobiology allow the use of both collections of spectra and lists of waveband definitions in the same call. We can obtain a table (data frame) of effective and un-weighted daily exposures for three different action spectra, and three different bands of the spectrum, for unfiltered sunlight and sunlight filtered by three different filters in two statements. In the first statement (four top lines of code) we convolve the spectra and store the results in a 'collection of spectra'. In the second statement we calculate effective daily exposures, usually called effective doses, and also non-weighted daily energy exposures, saving the results to `results`. All results are in

```
spectra <- source_mspct(list(sun=sun.daily.spct,
                             UVAB=sun.daily.spct * etola.mspct$Clear_LD_PE_50um,
                             UVA=sun.daily.spct * mcdermit.mspct$Autostat_CT5_125um,
                             UV0=sun.daily.spct * rosco.mspct$UV_filter_EColour226))
result <- e_irrad(spectra, list(CIE=CIE(), GPAS=GEN_G(), PG=PG(),
                                UVB=UVB(), UVA=UVA(), PAR=PAR()))
result

## Source: local data frame [4 x 7]
##
##   spct.idx      CIE      GPAS      PG       UVB     UVA     PAR
##     (fctr)    (dbl)     (dbl)   (dbl)     (dbl)   (dbl)   (dbl)
## 1      sun 2494.149 2.787e+03 23778.2 1.918e+04 1057512 7962841
## 2     UVAB 2173.369 2.412e+03 20979.7 1.667e+04  936883 7189580
## 3      UVA  595.829 1.848e+01 17257.1 5.043e+02  872743 7330173
## 4      UV0    9.875 2.787e-02   209.6 1.918e-01   66799 7027307
```

In the code above we have applied equation 8.1 24 times to obtain a table.

Box 8.6: Example code for reading a data file with spectral data output by Macam's software. We additionally print and plot the spectral irradiance data to demonstrate that also some metadata like units of expression as been also inferred or acquire from the file read.

Read, print, summarize and plot spectral data from a .DTA file from a Macam's spectroratiometer.

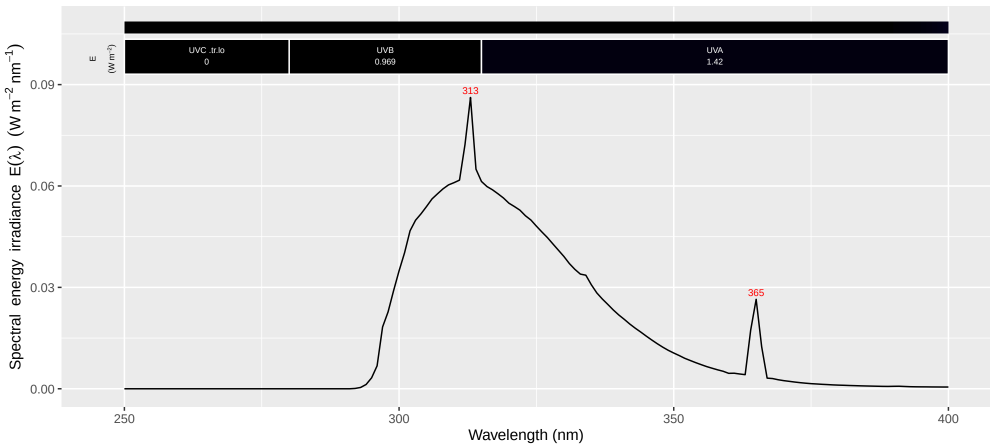
```
QP_UVB313.spct <- read_macam_dta("PLUS20-1.DTA")
print(QP_UVB313.spct)

## Object: source_spct [151 x 2]
## Wavelength (nm): range 250 to 400, step 1
## Time unit: 1s
##
##    w.length s.e.irrad
##       (dbl)     (dbl)
## 1       250         0
## 2       251         0
## 3       252         0
## 4       253         0
## 5       254         0
## ..      ...       ...

summary(QP_UVB313.spct)

## Summary of object: source_spct [151 x 2]
## Wavelength (nm): range 250 to 400, step 1
## Time unit: 1s
##
##     w.length     s.e.irrad
##  Min.   :250   Min.   :0.00000
##  1st Qu.:288   1st Qu.:0.00000
##  Median :325   Median :0.00241
##  Mean   :325   Mean   :0.01580
##  3rd Qu.:362   3rd Qu.:0.02746
##  Max.   :400   Max.   :0.08619

plot(QP_UVB313.spct)
```



reproducibility of UV research with plants, was what lead to my decision of spending a considerable proportion of my work (and free) time on the development of the suite.

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■ Answers to frequent questions

On ORCIDs, DOIs and repositories

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DOI:xxxxxxxxxxxxxxxx

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Coming in the Spring issue

We are already looking forward to the next issue. Some planned articles with tentative titles:

- Why is it so difficult to measure UV-B radiation in sunlight? Pedro J. Aphalo.
- TBA, Alan Jones.
- Experiences of a researcher temporarily turned into a science reporter, Nicole Regier.
- TBA, Javier López-Abaigar.
- Visible-blind broadband UV detectors and spectrometers by TBA.
- The r4photobiology suite: day length, Pedro J. Aphalo.
- Students' accounts of exchange and placement experiences:
  - An EPPN-funded series of experiments in the solar simulators: what we learnt from our visits to Munich, Neha Rai, Yan Yan and Sari Siipola.
  - Masters studies and thesis research in a foreign country: my experience in Finland, Mokabe Itoe.
- Regular columns:
  - Conference reports.
  - Historical accounts.

We warmly invite readers to submit their manuscripts to our open-access serial publication, so we hope to also have your own contribution for future issues.

UV4Plants

The International Association for Plant UV Research

Key aims of the UV4Plants international association are to

- promote and foster research-excellence and good practice in plant UV research through the organisation of innovative events in research, public engagement and education
- provide channels for members to inform the plant UV research community about relevant activities or events of common interest
- enhance the usefulness of plant UV research by facilitating the transfer of knowledge from academia to stakeholders and the general public
- initiate and foster stakeholder contacts as part of an agenda of product development
- liaise with scientific funding bodies to influence their research agenda
- develop with its members the benefits of membership and the relevance of the Association

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A new association with a history The origin of UV4Plants was the very successful COST Action FA0906 'UV4Growth' which was active from 2009 to 2014. It brought together photobiologists, molecular biologists, ecologists, meteorologists and stakeholders from agriculture and industry. Many new collaborations were started and new ideas developed.

Three large conferences, and several workshops and training events were organized. Four special journal issues were produced: *Physiologia Plantarum* **145**, 4, *Emirates Journal of Food and Agriculture* **24**, 6, *Plant Physiology and Biochemistry* **93**, and *Plant, Cell & Environment* **38**, 5.

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